Influence of climate on radial growth of *Abies pindrow* in Western Nepal Himalaya

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This study aims to understand the influence of climate on radial growth of *Abies pindrow* growing in the plateau of mixed forest in Khaptad National Park in Western Nepal Himalaya. Based on the dated tree-ring samples, 362-year long tree-ring width chronology was developed dating back to 1650. The studied taxa of this region was found to have dendroclimatic potentiality that was evident from the chronology statistics calculated. The tree-ring chronology was correlated with climate (temperature and precipitation) data to derive the tree-growth climate relationship. The result showed significant negative relationship with March-May temperature and positive relationship with March-May precipitation. This indicates that the availability of moisture is the primary factor in limiting the tree growth.

Key words: *Abies pindrow*, tree-ring, climatic influence, Khaptad National Park, pre-monsoon

Earth's climate has never been static and has shown great variability since its origin, the recent change, however, is accelerated by enhanced greenhouse effect causing abrupt temperature rise and unpredictable patterns of precipitation (Houghton, 2004). Feedbacks of climate change are reflected in several components of earth including air, water, ice, land and vegetation which have distinctive response time to the changing climate and the natural archives like tree rings, ice cores, sediments, pollens, etc can be used as proxies to reconstruct the past climatic variations (Ruddiman, 2000). Tree rings, in particular, the ring-widths respond to the climate and hence provide the basis for reconstructing past climatic variation (Fritts, 1976). In order to explore year-to-year as well as seasonal variation in climate, tree rings are most suitable proxies as they provide absolute dates with high annual resolution rather than giving relative estimates like other proxies (Fritts, 1976; Hughes and Diaz, 2002).

In the last decade, a number of dendro chronological studies from Nepal Himalaya have been conducted. However, most of these studies are from Central and Eastern Nepal Himalaya (Cook *et al.*, 2003; Bhuju *et al.*, 2010; Chhetri and Thapa, 2010; Gaire *et al.*, 2011; Dawadi *et al.*, 2013). There is a dearth of such works in Western Nepal Himalaya, though this part of Nepal Himalaya has huge potential for tree-ring research (Suzuki, 1990; Bhattacharyya *et al.*, 1992). *Abies pindrow* has been reported to have dendroclimatic potential in Western Himalaya (Borgaonkar *et al.*, 1994; Borgaonkar *et al.*, 1999; Bhattacharyya *et al.*, 2001; Yadav and Singh, 2002). It has been reported that radial growth of *A. pindrow* in Western Himalayan region are limited by pre-monsoon climate (Borgaonkar *et al.*, 1999; Yadav and Singh, 2002). Similar response has been noted in the ring-width analysis of *A. spectabilis* in Nepal Himalaya (Sano *et al.*, 2005; Gaire *et al.*, 2011).

A. pindrow is a low altitude Himalayan fir

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stretching from Afghanistan to Pakistan distributed in the range of 7,000–10,000 ft above sea level, it is confined to northern and western aspects of the slopes (Stainton, 1972). Unlike *A. spectabilis*, it does not extend up to tree line. In Nepal Himalaya, it is most abundant in Humla District found either in a single stand or with other taxa such as *Picea smithiana* and *Betula utilis* (Stainton, 1972). Despite of its abundance in Western Nepal, only few preliminary attempts have been made till date to explore the dendroclimatic potential of this taxa.

This study was carried out in order to extend the scientific information in Western Nepal Himalaya with defined objectives of developing the ring-width chronology of *A. pindrow* and examining the influence of climate on its radial growth.

Materials and methods

Study site and sample collection

The tree core samples of *A. pindrow* were collected from the Khaptad Plateau Forest in the Khaptad National Park (KNP) in Far-Western Nepal located at an altitude of 3,000 m (Fig. 1). Sampling was carried out in September 2012 where 60 cores from 30 trees (two cores from each) were extracted at breast height (1.37 m) using Swedish Haglöf Increment Borer.

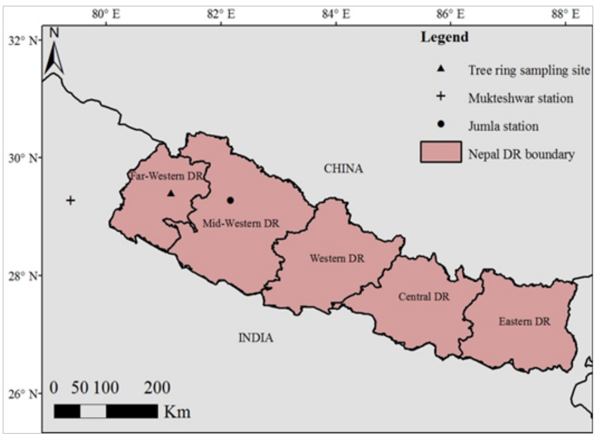

Fig. 1: Development Region map of Nepal showing study area with tree ring sampling site and meteorological stations

Sample preparation and tree-ring chronology development

The collected samples were air dried in the tree-ring labouratory at Nepal Academy of Science and Technology (NAST). The dried samples were mounted in the wooden frame with the cross-sectional view facing upward followed by sanding and polishing the surface manually through grades of progressively finer grit sand papers until the ring boundaries were clearly visible under binocular microscope. Each ring was counted and dated to the calendar year of their formation using skeleton plot technique of crossdating (Stokes and Smiley, 1968). Ring width of each series was then measured using LINTAB measurement system with a LINTAB moving stage and a stereomicroscope, attached to PC having TSAP-Win program. Accuracy of measurement and dating was examined using program COFECHA (Holmes, 1983) and the corrections were again re-examined to check the presence of any further error. Each series was standardized using computer program ARSTAN in order to remove the age trends in the dated series. A 30-year cubic smoothing spline was fitted for standardization and finally a standard ring-width chronology was developed. Autocorrelation present in the standard chronology was removed with the help of autoregressive (AR) modelling to develop residual chronology.

Climatic data

The climatic record was obtained from Jumla Station (29°28'N, 82°16'E) located at 2300m which is around 92 km east from the study site. Both the temperature and the precipitation of this station contained sufficient period of record ranging from 1969 to 2012 and from 1956 to 2012 respectively, but with some missing data. Therefore, the climatic record from Mukteshwar Station (29°28'N, 79°39'E) located at an altitude of 2,311 m in India which is around 140 km west from the sampling site and has relatively longer period of climate data (1897–2011) was also collected. Correlation between the climate data of these two stations revealed that temperature and precipitation were significantly correlated at 0.05 confidence level ($n = 43$) and 0.01 confidence level ($n = 55$) respectively. Thus, climate data from Mukteshwar Station was used for further analysis. The climate record of Mukteshwar Station for a period of 1897–2011 showed that May, June and July were the warmer months whereas November and December were the cooler months. Similarly, higher precipitation was experienced in July and August whereas lesser rainfall occurred during November and December (Fig. 2).

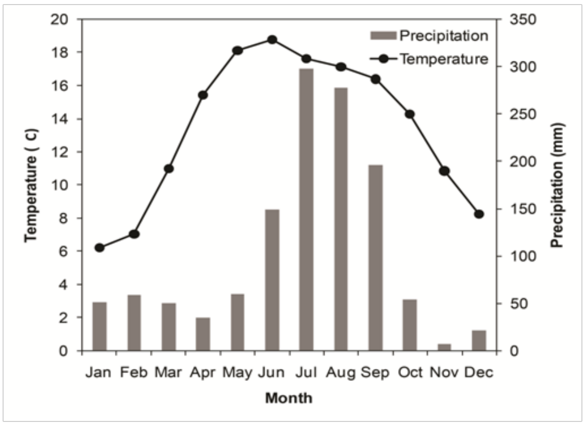

Fig. 2: Mean monthly temperature and total monthly precipitation at Mukteshwar Meteorological Station based on the data of 1897–2011

Tree growth / climate relationship

Correlation analysis was used in order to derive the relationship between ring growth and climate. For this, temperature and precipitation data were used as predictor and residual ring-width chronology as predict, and analysis was carried out in DENDROCLIM2002 (Biondi and Waikul, 2004). The degree of association was measured in terms of correlation coefficient and its significance was tested using difference between 97.5 and 2.5 percentile.

Results and discussion

Tree-ring chronology characteristics and statistics

Among the 60 cores collected from *A. pindrow*, 36 cores from 22 trees were successfully cross dated. The cores which were broken during collection and transportation were difficult to date and were discarded for analysis. A 362-year long ring-width chronology of *A. pindrow* was developed extending from 1650 to 2012 which is shown in figure 3.

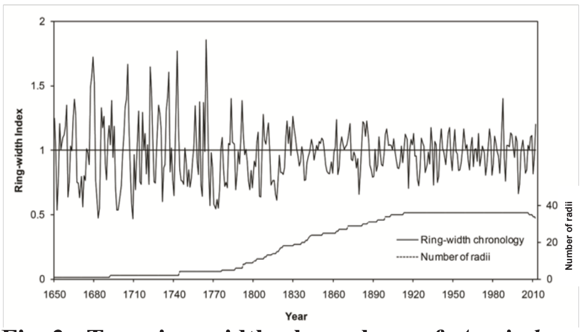

Fig. 3: Tree-ring width chronology of *A. pindrow* extending from 1650 to 2012 along with the number of radii

The average annual radial growth of *A. pindrow* was 1.361 mm. The values of mean sensitivity were 0.176 and 0.194 for standard and residual chronologies respectively. First order autocorrelation decreased to 0.047 in residual chronology, as autocorrelation was removed from standard chronology to get residual chronology. The value of first order autocorrelation in standard chronology was found to be 0.426. The standard deviations were 0.219 and 0.191 for standard and residual chronologies respectively. The dated series had a mean correlation of 0.435 with the master chronology. The number of absent rings encountered was 13, amounting to 0.193% of the total rings analyzed.

Other statistical parameters were also calculated for the common period (1871–2006) of the chronology. The mean correlations within the trees, between the trees and among all radii were estimated. High values of correlation coefficients within the trees were recorded for both the chronologies (about 0.6); however, the coefficient was less for between the trees and among all radii (<0.2). Both chronologies well exceeded the Expressed Population Signal (EPS) limit of 0.85 indicating that the site chronology well represented the population chronology (Wigley *et al.*, 1984). Though, the ring-width chronology extended since 1650; however, it crossed the EPS limit of 0.85 only after 1843 with 24 core series. Signal to Noise Ratio (SNR) in standard chronology was found to be 6.948 which increased to 7.592 after applying AR modelling. The variance explained in first eigen-vector was 23.5% and 25% respectively for standard and residual chronologies indicating strong common signal. The chronological statistics of both standard and residual chronology for the entire period as well as for the common period are given in the table 1.

Climate influence on tree-growth

The correlation analysis carried out between residual ring-width chronology and climate revealed significant negative relationship with the temperature of March, April and May whereas positive relationship with the precipitation of the same three months (Fig. 4).

Climate data showed that there was abrupt rise in temperature with sharp decline in rainfall during the beginning of pre-monsoon (Fig. 2)

Table 1: Chronological statistics of site chronology of *A. pindrow* from Khaptad National Park

Chronology statistics	Standard chronology	Residual chronology
Chronology span (years)	1650-2012 (362)	1650-2012 (362)
Number of trees (radii)	22 (36)	22 (36)
Mean sensitivity	0.176	0.194
Standard deviation	0.219	0.191
1st order autocorrelation	0.426	0.047
Common period analysis (1871-2006)		
Correlation among all radii	0.193	0.207
Correlation between trees	0.180	0.196
Correlation within trees	0.628	0.589
Signal to Noise Ratio (SNR)	6.948	7.592
Expressed Population Signal (EPS)	0.874	0.884
Variance in PC1 (%)	23.5	25.0

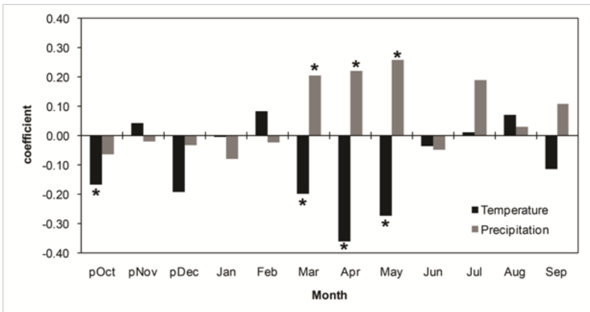

Fig. 4: Correlation function plot of *A. pindrow* showing tree-growth climate relationship. Significant climatic months influencing the growth is shown by * marks

making soil moisture stressed during the entire pre-monsoon season limiting the growth. Similar climatic response has also been recorded in the ring-widths of same as well as other species in Western India Himalaya (Borgaonkar *et al.*, 1994; Borgaonkar *et al.*, 1999; Pant *et al.*, 2000; Yadav *et al.*, 2004). Even, *A. spectabilis* in Western and Central Nepal (Sano *et al.*, 2005; Chhetri and Thapa, 2010; Gaire *et al.*, 2011) as well as *B. utilis* in Central Nepal (Dawadi *et al.*, 2013) have recorded the similar climatic signals in their ring-widths.

However, different responses were also shown by several conifers in Eastern India Himalaya and Tibetan Plateau as compared to that shown by *A. pindrow* in this site. In Eastern Himalaya, Bhattacharya and Chaudhary (2003) reported that temperature was positively related with radial growth of *A. densa*. Similarly, in Tibetan Plateau, temperatures of various seasons were found to be directly correlated with the growth whereas precipitation was either insignificant or indirectly limiting the growth of several species examined (Liang *et al.*, 2008; Li *et al.*, 2011). This might be due to different monsoon system and rain shadow effect in the Tibetan Plateau.

Conclusion

Tree-ring width chronology of *A. pindrow* spanning over 362 years dating back to 1650 was developed from Western Nepal Himalaya and its dendroclimatic potentiality was discussed on the basis of chronology statistics. Pre-monsoon climate was found to be detrimental in the growth of this species; however, further study with increased sample size is essential for further reconstruction of pre-monsoon temperature as well as precipitation in Western Nepal Himalaya.

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